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LANDS, PARKS AND FORESTS BRANCH
DOMINION FOREST SERVICE
Canada FOREST PRODUCTS LABORATORIES

STRENGTH OF DOWEL JOINTS

BY

GEORGE L. ROSSER

OTTAWA, CANADA
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DEPARTMENT OF MINES AND RESOURCES
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I. INTRODUCTION

Dowel joints, assembled under varying conditions of gluing, have been submitted to the Forest Products Laboratories by manufacturers of furniture and other commodities for a determination of their resistance to withdrawal. Requests have also been received from Canada and from abroad regarding the relative suitability of different Canadian woods for the manufacture of dowel.

Very little information was available for dealing adequately with these inquiries; an investigation was undertaken, therefore, with a view to obtaining data on the more important problems attending the manufacture of dowel and its use in joint assemblies. Particular attention was paid to the effect of different glues and different moisture contents of the dowels on the strength of the dowel joint.

Sugar maple, paper birch, and yellow birch dowels were received from different sources. The data obtained from the tests, together with a discussion of the factors which have an influence on the strength of the joint, are presented hereunder.

II. MATERIALS USED

1. SPECIES

White oak, red oak, and yellow birch were used for the dowel heads; these were prepared as shown in Figures 1 and 2. The dowels, which measured one-half inch, more or less, in diameter, were of sugar maple, yellow birch and paper birch. The letters appearing in Table 1 indicate the species and the sources from which the dowels were obtained. Each lot of dowel material was received from a different manufacturer, excepting c and d, both of which were supplied by one company. For the butt-joint assemblies yellow birch was used.

2. ADHESIVES

Commercially prepared water-resistant casein glue, hide glue (viscosity 156 millipoises, jelly 589 grams), and graded animal glue (viscosity 38 millipoises, jelly 69 grams) were used for the assemblies. The casein was mixed with cold water according to the manufacturer's instructions; the animal glues were mixed in a ratio of 100 grams of dry glue to 250 cc. distilled water and were spread at 60°C.

Table 1. Moisture Content and Shrinkage of Dowel

Dowel identification		x	b	c	d	e	f
Species		Sugar Maple	Sugar Maple	Sugar Maple	White Birch	White Birch	Yellow Birch
Per cent moisture (as received)		10.2	16.7	14.4	8.8	7.4	11.5
Diameter - inches (as received)	Radial	0.499	0.503	0.495	0.502	0.504	0.503
	Tangential	0.492	0.499	0.497	0.502	0.504	0.504
	Average	0.4955	0.5010	0.4960	0.5020	0.5040	0.5035
Diameter - inches (oven-dry)	Radial	0.489	0.488	0.482	0.489	0.494	0.490
	Tangential	0.476	0.471	0.476	0.486	0.492	0.488
	Average	0.4825	0.4795	0.4790	0.4875	0.4930	0.4890
Per cent shrinkage (oven-dry = 100)	Radial	1.9	2.9	2.8	2.6	2.1	2.7
	Tangential	3.3	5.8	4.3	2.4	2.4	3.2
	Average	2.60	4.35	3.55	2.50	2.25	2.95
Relative descending order of dowel based on average diameters, oven-dry condition.		4	5	6	3	1	2

Table 2. Average depth of insertion of dowel

Glue	Assembly	Direction of dowel to grain of dowel head: Parallel	Perpendicular
		Depth, inches	Depth, inches
I	A	1.21	1.19
II	A	1.24	1.25
III	A	1.24	1.25

III. METHODS OF PREPARATION AND ASSEMBLY

1. MOISTURE AND SHRINKAGE DETERMINATIONS

From each shipment of dowels a number of sections were cut and marked for radial and tangential measurements. The measurements were made as soon as possible after the material was received at the Laboratories. Each section was weighed and placed in an electric oven, controlled at 100°C, until it reached constant weight. Measurements were made over the original radial and tangential diameters as soon as the sections were finally removed from the oven. Moisture contents and shrinkage were calculated and the average results are given in Table 1. The considerable variation in moisture content of the shipments is to be noted.

2. PREPARATION OF DOWEL-HEADS

Dowel heads, the dimensions of which are given in Figures 1 and 2, were prepared from material at approximately 7.5 per cent moisture. The heads were dried to 5 per cent moisture and then were bored to a depth of 1.25 inches with a one-half inch bit fitted to a wood boring machine.

3. ASSEMBLY

(i) Dowel joints

Four methods were used in the assembling of dowel joints. These are denoted in the tables, respectively, by the letters A, B, C, and D.

In method A, the glue solution was spread in the dowel-hole and on the end of the dowel to be inserted.

In method B, the glue solution was spread in dowel-hole only.

In method C, the glue solution was spread in dowel-hole and on end of dowel to be inserted. A three-quarter inch barbed roofing nail was driven into the insertion end of the dowel, parallel to grain, to a depth just sufficient to retain the nail in position. The dowel was then inserted into the hole and driven against the nail.

In method D, glue was spread in the dowel-hole and on the end of the dowel to be inserted. A corrugated metal fastener, one-half inch in depth, and three-eighths inch in length, was started into the insertion end of the dowel, parallel to grain. The dowel was then inserted into the dowel-hole and driven against the corrugated fastener.

(ii) Driving force

All dowel was driven into position by successive blows of a carpenter's hammer.

(iii) Butt-joints

Butt-joints were assembled under a pressure of 200 pounds per square inch and ripped into test sections as shown in Figure 3.

IV. MECHANICAL TESTS

1. DOWEL-JOINTS

The dowel-head was held in a metal sling and the dowel-stem in grips, both of which were attached to a Universal testing machine. A tensile strain was applied, at a constant rate of loading, parallel to the grain of the dowel, until failure occurred. The load at failure and the percentage of failure which occurred in the wood were recorded for each section tested.

2. BUTT-JOINTS

The butt-joint sections, Figure 3, were held in grips attached to a Universal testing machine. The rate of loading was constant for all tests and the load was applied parallel to the grain of the test-piece and perpendicular to the glue-line. The load at failure and the percentage of wood failure were recorded for each section tested.

3. MOISTURE CONTENTS AT TEST

Mechanical tests were made on assemblies at three moisture contents:

(i) One per cent

Dowel assemblies were dried in an electric oven at 100°C. for two weeks and then cooled to laboratory temperature before testing.

(ii) Seven per cent

Assemblies were placed in a humidity oven, controlled at 7 per cent moisture. Determinations were made at intervals on dowel assemblies used as controls, and the mechanical tests when the controls reaches 7 per cent moisture.

(iii) Twelve per cent

Assemblies were placed in a humidity-controlled room until the average moisture content of the control assemblies reached 12

per cent.

(iv) Moisture determinations at time of test

Moisture determinations on joints were made immediately after mechanical tests and these showed that the actual moisture contents were sufficiently close to the required one per cent, seven per cent and twelve per cent for the purposes of this investigation.

4. RELATED FACTORS

After the determination of its mechanical strength the head of each individual assembly was split open. The depth to which the dowel was originally driven was measured, correct to a hundredth of an inch, and the measurement recorded. The inserted end of the dowel was examined, and an estimate of the amount (in per cent) of wood fibre adhering to, or torn from, the dowel was also recorded. The average depth in inches for all tests on each glue are given in Table 2, page 2.

V. DISCUSSION OF RESULTS

1. TEST AVERAGES

All results given in the tables represent an average of at least five tests unless indicated otherwise.

2. LEGEND

The numerals and letters in the first column of each table denote the adhesive used, the method of assembly, and the species and source of the dowel. Numerals are used to indicate the adhesive, as follows: I. Casein; II. High-grade Animal Glue; and III. Graded Animal Glue. Further information on the adhesive used is given under Section II. Materials used, 2, Adhesives. The significance of the capital letters A, B, C and D is discussed under Section III Methods, 3, Assembly. The small letters represent the dowel species, as shown in Table 1, Page 2.

3. DOWEL MANUFACTURE

There appears to be no standard moisture content for dowel material at time of manufacture. The dowel machine produces dowel of a given diameter and does not permit of adjustment to allow for the shrinkage which occurs in the change from air-dry conditions (12 to 18 per cent) to the minimum moisture in heated buildings (approximately 5 per cent). Air-dry material (as noted

above) may be of any moisture content from 12 per cent to well above 16 per cent, and between these limits and 5 per cent moisture content considerable shrinkage occurs. Dowel b, Table 1, was received at a moisture content of 16.7 per cent; when oven-dry its average tangential diameter was reduced by 0.028 inches. It is to be noted that the dowel hole at time of boring is fractionally greater in diameter than the maximum diameter of the boring tool. A decrease in dowel diameter, coincident with an increase in dowel-hole diameter, prevents the development of pressure essential to strong joints.

4. FACTORS GOVERNING INSERTION

The depth to which dowel can be inserted in a dowel hole is governed by the viscosity of the adhesive at the time of insertion, and by the relationship which exists between the radial and tangential diameters of the dowel and of the dowel-hole.

(i) Viscosity of the adhesive

The depth of insertion was measured for each test assembly and it is to be noted that, in many instances, the dowel had not been driven to a full depth of 1.25 inches. Examination showed that a much greater force is necessary to drive dowel to a full depth with casein glue than with animal glue solutions. Surplus casein glue did not escape around the dowel but formed a cushion at the bottom of the dowel-hole which effectively withstood the driving force applied to the dowel. Surplus glue from animal-glue solutions passed more freely around the dowel and made possible a higher per cent of insertions to full depth. (Table 2, Page 2).

(ii) Size of dowel in relation to size of dowel hole.

If the dowel, before the glue solution is applied, fits snugly into the dowel-hole the application of the aqueous solution of glue will cause a slight superficial swelling of the wood and a resultant pressure on the glue line, but with close fitting dowel the problem of permitting surplus glue to escape will emerge. With no means of escape the surplus glue will form a cushion at the bottom of the dowel hole that will effectively resist pressure. An examination of the fractured joints indicates that a tight-fitting dowel assembly is essential to strong joints and that some avenue of escape for surplus glue should be provided. It would appear that insertion of closely fitting dowel to full depth would be facilitated by the use of spiral-grooved dowel. (1)

(iii) A standard for comparison necessary.

The variations in the depth to which the dowel was driven necessitated the adoption of a standard so that comparisons could

be made. Dowel, one-half inch in diameter, inserted to a depth of 1.25 inches, is equivalent to a glue line of 1.96 inches. In this computation the cross-sectional area at the end of the dowel has been ignored because it does not meet a suitable gluing surface at the bottom of the dowel hole. Computations were made for each test so that all results could be compared on the basis of one square inch of glue line and the results given in the tables represent the loads at failure for that area.

5. FACTORS GOVERNING MECHANICAL STRENGTH

(i) Variability in strength of wood.

Consistency of failure in wood joints is not to be expected. The strength of wood is variable within any given species and investigation has shown that 93 per cent of the mechanical test values fall within a range of 25 per cent above or below the average value. (2). In selecting material for mechanical tests on glued joints, there is no means of determining beforehand how far the actual strength will deviate from the mean value for the species. White oak, I-A-f assembly, parallel insertion, tested at one per cent moisture, gave an average strength of 478 pounds per square inch with a wood failure of 42 per cent, whereas the lowest failure in that series occurred at 342 pounds per square inch with a wood failure of 60 per cent. Assembly II-A-x, white oak, parallel insertion, tested at seven per cent moisture, developed an average strength of 406 pounds per square inch with wood failure of 44 per cent, whereas the minimum was 319 pounds per square inch with 60 per cent wood failure.

(ii) High grade glue necessary.

A general consideration of the values in Tables 3 to 5 indicates that high-grade glues are essential for assembly of dowel-joints. At the low moisture content of one per cent the casein assemblies were strongest. The average for all tests in each glue assembly have been computed. Glue III, a graded glue of low viscosity and jelly strength, gave an average for all tests in A series, perpendicular to grain assembly, of 85 pounds per square inch when tested at one per cent moisture, and B Series, perpendicular to grain and at one per cent moisture, of 91 pounds per square inch. A much greater resistance to withdrawal loads is necessary for joints in furniture under ordinary conditions of use.

Another factor associated with glue of poor quality is its tendency to craze in atmospheres of low humidity. It is difficult to determine whether or not crazing developed in the joints under consideration, but in tests made on shear assemblies microscopic examination of the fractured joints showed that crazing does result

Table 3. Average strength of dowel assemblies for each species. Glue I, Assembly A.

Mark	Species	1 per cent moisture				7 per cent moisture				12 per cent moisture			
		Direction of insertion: grain of dowel to grain of dowel-head											
		Parallel		Perpendicular		Parallel		Perpendicular		Parallel		Perpendicular	
		lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF
1-A-x	White oak	693	38	176	0	716	23	630	0	751	43	640	2
-b		536	44	149	2	497	32	531	2	621	61	543	1
-c		518	55	181	0	572	37	423	4	645	63	487	1
-d		466	52	210	3	692	29	643	5	604	53	628	4
-e		503	32	247	0	704	32	523	0	565	55	575	0
-f		478	42	259	5	668	29	574	0	660	57	604	0
-f	Red oak	540	39	245	2	622	36	518	1	710	47	600	4
-x	Yellow birch	410	11	201	0	553	19	416	5	690	24	383	5
-f		538	28	285	5	681	19	422	3	750	22	435	0

WF - Wood failure.

Table 4. Average strength of dowel assemblies for each species. Glue II, Assembly A.

Mark	Species	1 per cent moisture				7 per cent moisture				12 per cent moisture			
		Direction of insertion: grain of dowel to grain of dowel-head											
		Parallel		Perpendicular		Parallel		Perpendicular		Parallel		Perpendicular	
		lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF
II-A-x	White oak	361	47	217	11	406	44	306	6	574	64	630	2
-b		317	31	224	10	416	45	315	4	622	57	586	13
-c		290	60	132	8	361	44	365	0	632	51	711	5
-d		377	18	190	0	413	9	308	0	518	10	539	4
-e		390	36	204	6	449	7	319	0	762	13	610	6
-f		401	74	170	4	457	56	390	4	667	71	600	2
-f	Red oak	555	77	243	8	569	33	479	3	914	39	721	5
-x	Yellow birch	360	26	199	4	419	23	399	6	743	30	655	5
-f		466	58	199	2	522	26	366	0	680	30	606	2

WF - Wood Failure.

Table 5. Average strength of dowel assemblies for each species. Glue III. Assembly A.

Mark	Species	1 per cent moisture				7 per cent moisture				12 per cent moisture			
		Direction of insertion: grain of dowel to grain of dowel-head											
		Parallel		Perpendicular		Parallel		Perpendicular		Parallel		Perpendicular	
		lbs. per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF
III-A-x	White oak	364	54	68	0	523	20	358	8	645	16	551	1
-b		314	41	106	0	463	23	342	5	722	23	672	0
-c		301	46	65	0	428	20	377	2	808	27	429	0
-d		314	8	78	0	479	8	291	1	754	18	558	0
-e		294	6	97	0	551	15	360	0	771	25	478	0
-f		304	28	91	0	610	45	331	2	624	28	628	3
-f	Red oak	230	27	72	0	590	43	476	4	768	46	731	2
-x	Yellow birch	213	15	81	0	499	33	298	13	736	33	509	1
-f		374	14	107	3	535	26	306	14	495	20	657	1

WF - Wood Failure

when low-quality animal glues are dried in an electric oven at 100 degrees C. to constant weight.

(iii) Single and double spread

A comparison of results given in Table 6 with those in Tables 3, 4 and 5 indicates the general advantage to be derived from double-spread of glue. Examination of fractured joints showed that in single-spread assemblies considerable areas of the inserted end of the dowel were unaffected by the glue. In perpendicular to grain assemblies glue is rapidly absorbed by the end-grain areas of the dowel-hole, and in a large number of joints the dowel adjacent to the end-grain had no effective contact with the glue. With double-spread assemblies a greater quantity of glue reaches the end-grain areas, and some adhesion is to be expected. It is to be noted that in a few cases Assembly B developed greater resistance to loading than did Assembly A, and an example is to be found in Glue I, dowel f, white oak (Table 6), where B was stronger by 18 pounds per square inch than A (Table 3). Reference to the wood failure column indicates that the wood used in the B Assembly was stronger than that used for the A Assembly.

(iv) Shrinkage of wood

Table 1 and Graph 1 indicate the reductions in diameters of dowel which occur when the moisture content of wood is reduced to oven-dry condition. It is to be noted that in cross-section the dowel, in air-dry condition, is a mechanically perfect circle when leaving the dowel machine, but that it assumes an elliptical form in drying. The rate of radial shrinkage of wood differs from its tangential shrinkage, and this difference for dowels is indicated in Graph 2. The small letters used in the graphs correspond to those used in Table 1 to designate the species. It appears that the strength of dowel-joints would be improved by using dowel machined at low moisture content, because the shrinkage which occurs in reducing moisture content from 5 per cent to oven-dry condition, is very small. It is to be noted, further, that the average diameter of dowel holes at the time of boring is fractionally greater than the greatest diameter of the boring tool. This greater diameter, in conjunction with dowel shrinkage, results in loosely fitting joints and in poor adhesion. Dowel C had the smallest average diameter in the oven-dry condition, and Tables 3 to 5 show that this dowel, tested at one per cent, offered low resistance to withdrawal loads.

(v) Species in relation to strength

If all dowel is run at 12 per cent moisture, it would appear that white birch, because of its lower shrinkage coefficient,

Table 6. Average strength of dowel assemblies for each species. Assembly B.

Mark	Species	1 per cent moisture				7 per cent moisture				12 per cent moisture			
		Direction of insertion: grain of dowel to grain of dowel-head											
		Parallel		Perpendicular		Parallel		Perpendicular		Parallel		Perpendicular	
		lbs. per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF
I-B-f	White oak	496	25	169	0	567	31	327	4	486	30	477	0
-f	Yellow birch	447	22	97	0	494	24	325	6	655	10	441	2
II-B-f	White oak	336	40	167	9	371	37	301	4	444	16	435	3
-f	Yellow birch	333	24	176	7	447	26	312	2	478	16	405	1
III-B-f	White oak	214	23	82	0	490	30	299	2	418	19	413	1
-f	Yellow birch	228	6	99	12	379	12	273	28	450	16	476	1

WF - Wood Failure

ger joints than would yellow birch or
s indicate that species does not
joint strength. In no single in-
owel joint reach the average strength
the assembly. It is to be noted that
lowel were well manufactured, wi
rellow birch dowel had a rough,
oint strength does not appear t
but with the relationship whic
e dowel and of the dowel hole at the

d joints with aqueous glue solutions,
se of pressure is to bring surfaces
and excess glue from the joint; to
to secure intimate contact between
cent to the glue line; to hold
the glue sets (3).

"the strength of a glued joint varies
applied up to about 1,000 pounds per
tion is large" (4). It is not poss-
oints by ordinary assembly methods.
ng of the wood which follows the
n of glue or is developed by an
D assemblies. In any event it is
fit snugly into the unglued dowel-
ot exerted on the glue line when the
ints are not to be expected.

ith wood can be considered stronger
lies particularly to complex assem-
he rungs are inserted perpendicular
The low minimum resistance to with-
for insertions perpendicular to grain
hrinkage coefficient for individual
ted to produce unusually low with-
the extremely low resistance of 21
one test section of Series III-A-c,
ain and tested at 1 per cent moisture.

joint strength.

for the purpose of developing press-
pled joint. The barbed roofing nail,
ry because it offered too great re-
ny instances crushing of the end of
applied occurred, but an increase
he adoption of this method (compare

Table 7. Average strength of dowel assemblies for each species. Assemblies C and D.

Mark	Species	1 per cent moisture				7 per cent moisture				12 per cent moisture			
		Direction of insertion: grain of dowel to grain of dowel-head											
		Parallel		Perpendicular		Parallel		Perpendicular		Parallel		Perpendicular	
		lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF	lbs per sq. in.	% WF
I-C-f	White oak	553	63	246	2	531	55	431	2	508	13	478	0
-f	Yellow birch	643	70	205	3	723	77	622	10				
I-D-f	White oak	719	63	425	4	657	27	514	12	757	56	744	18
-f	Yellow birch	702	49	416	29	773	25	679	21	912	36	865	13
II-D-f	White oak	671	70	399	26	754	45	615	28	866	51	865	7
-f	Yellow birch	662	67	320	16	555	38	613	28	664	33	826	13
III-D-f	White oak	618	47	330	16	736	53	734	20	625	20	788	1
-f	Yellow birch	635	32	406	26	729	57	723	44	717	20	691	8

WF - Wood Failure

Table 7 with Tables 3, 4, 5 and 6). For reasons given above the tests were not continued beyond those indicated in the Table.

The results of tests on Assembly D, Table 7, using corrugated metal fasteners, showed considerable improvement in joint strength over Assemblies A and B. The corrugated fastener formed a wedge which split the end of the dowel sufficiently to cause pressure to be exerted on the glued surfaces. A comparison of the results given in Table 7, Assembly D, with those given in Tables 3, 4, 5 and 6 will indicate considerable improvement in strength of perpendicular assemblies at one per cent moisture when assembled with a corrugated fastener. The average of all Assembly A tests when compared with all Assembly D tests shows that the latter method resulted in an improvement in joint strength to the extent of over 100 per cent. It would appear from these results that, where strength in dowel joints is desirable, some means of splitting the dowel end, so that pressure may be exerted on the glue line, could be utilized.

(ix) Moisture conditions

The wide spread between low and high temperature and humidity experienced in Canadian homes and offices during any consecutive twelve months has a very definite effect on wood joints. Atmospheric changes within a building cause changes in the wood. Protective finishes will prevent rapid change in the moisture content of furniture but slow change does occur. Much of the wood in furniture has no covering that offers effective resistance to moisture changes, and the wood readily adjusts itself to its atmospheric surroundings. Furniture covered with a fabric is usually assembled with wood in its natural state and to meet such conditions a strong glue that can adjust itself to moisture changes without loss of strength should be used, and the dowel joints should be reinforced in some manner that will exert pressure against the walls of the dowel-hole at the time of assembly.

(x) Dowel inserted parallel to grain

Joints with dowel inserted parallel to the grain gave better results than perpendicular assemblies. Gluing conditions are at their best when the grain of the two members forming the joint is in a longitudinal direction. The figures given in Table 2 indicate that greater depth of insertion was obtained from assemblies with the grain of the dowel parallel to the grain of the dowel-head than with assemblies having the grain of the dowel perpendicular to the grain of the dowel-head. It is to be noted that in many cases the average strength of the joints did not equal the average strength in shear (830 pounds per square inch) of the Canadian commercial species which offers the least resistance to shear stress.

(xi) Dowel inserted perpendicular to grain

The weakness of this form of assembly is indicated in the average loads at failure for A and B Assemblies when tested at one per cent moisture (see Tables 3 to 5). Examination of dowel holes showed that the gluing surface was not as clean as for holes bored parallel to the grain. The problem of gluing end-grain face to a tangential or radial

grain face also emerges. The difficulty of obtaining successful adhesion is increased by the tearing effect of the bit on the end grain. Under ordinary conditions of assembly the faces to be glued, whether radial, tangential or end-grain, would be surfaced on a planer, and good gluing surfaces provided. With a ragged end grain, and the further problem that the grain of the dowel runs perpendicular to the grain of the head, the production of strong joints at low moistures, under ordinary methods, is difficult.

(xii) Wood failure

Sugar maple is used for the standard tests to determine the mechanical strength of glued joints in shear and the load is applied directly over,and parallel to, the glued area. The strength of the glue is considered to be satisfactory if under stress, fracture occurs entirely in the wood adjacent to the glue line at a load of not less than 2330 pounds per square inch, this being the average strength in shear of air-dry sugar maple. Such fracture is recorded as 100 per cent wood failure. The average percentage of wood failure in tests on dowel joints was noticeably low, particularly in assemblies perpendicular to grain. A definite increase in wood failure occurred in Assembly D (compare Tables 3, 4 and 5 with Table 7). Absence of wood failure in dowel assemblies is to be considered as evidence that no efficient pressure was exerted on the glue line at time of assembly, or that the maximum strength of the glue was lower than that of the wood used in the assembly. Absence of pressure was probably the sole cause of the low percentage of wood failure.

6. BUTT-JOINTS

The results of tension tests on butt joints are given in Table 8. All fractures occurred in the glue-line without any wood failure. It is to be noted that the values are much higher than for dowel joints, and this is to be accounted for by (a) the effective pressure applied and (b) the smoothness of the faces of the joint.

Butt-joint assembly offers very low resistance to side thrust. Joints were assembled with Glues I, II, and III and prepared for testing as shown in Figure 3. The load was applied perpendicular to grain directly over, and parallel to, the glue line. The test sections were supported over a span of 12 inches. Failures occurred entirely in the glue at the following average loads in pounds per square inch: Glue I, 172; Glue II, 134; and Glue III, 132.

(i) Butt-joints assembled with dowel

From the results of tests on dowel and butt-joint assemblies it would appear that dowel is essential in butt-joints. The insertion of dowel although tending to decrease resistance to a tensile load, would greatly increase the resistance to thrust or to impact. Tests made in this investigation indicate that dowel would also strengthen joints made up with end grain on one face and tangential or radial grain on the other face of the joint.

Table 8. Strength of butt-joints tested in tension

Glue	Per cent of moisture at test	
	1 per cent	7 per cent
	lb./sq.in.	lb/sq.in.
I	1100	1172
II	1809	2815
III	855	964

VI. DOWELS IN FURNITURE AND JOINERY

1. EDGE-JOINT ASSEMBLIES

The insertion of dowel in assemblies in which the grain of both faces of the joint runs in the same longitudinal direction does not increase the strength of the joint. Tests made at these Laboratories on joints assembled with sugar maple and a good animal glue show that a resistance to shear stress of over 4,000 pounds per square inch is not phenomenal. The greatest load at failure for any individual dowel assembly tested in this investigation was 1262 pounds per square inch. When wood is assembled under optimum gluing conditions (i.e., with the grain of both faces parallel) the insertion of dowel, perpendicular to the grain, tends to reduce the average strength of the joint. On the other hand, dowel in edge-glued joints helps to prevent fracture of the wood adjacent to the glue line when the two adjacent boards, under stress resulting from moisture changes, tend to warp in opposite directions, but would have no beneficial effect on adjacent boards which warp in the same direction, and at the same rate of movement.

2. DOORS, WINDOW-SHUTTERS, ETC.

It would appear that dowel joints are unsuited to door, window-shutters, and similar assemblies because of: (a) the comparatively low strength of dowel joints and (b) the difficulty of obtaining satisfactory adhesion between end and flat- grain surfaces. Such assemblies are often submitted to a wide range of atmospheric conditions and the tests on dowel joints indicate that in order to withstand the stresses which such changes develop in wood, the mortise and tenon joint would prove of much greater practical value than the dowel joint.

VII. SUMMARY

1. White oak, red oak and yellow birch were used for dowel-heads - sugar maple, white birch and yellow birch for dowel - and yellow birch for butt-joints.

2. Casein and animal glues were used for the assemblies.

3. Dowel joints were assembled by four methods and a hand hammer was used to drive the dowel into dowel-holes. Butt-joints were assembled under a controlled pressure of 200 pounds per square inch.

4. A tensile load was applied by means of a universal testing machine. A constant rate of loading was used.

5. Tests were made on assemblies with moisture contents of 1 per cent, 7 per cent and 12 per cent.

VIII. CONCLUSIONS

1. Dowel should be manufactured at a moisture content of about 7 per cent to prevent undue shrinkage and a resulting loose fitting of the dowel in the dowel hole.

2. Dowel holes should be bored at a moisture content not exceeding 5 per cent.

3. Casein glue does not move around the dowel as freely as animal glues and, where the dowel fits snugly into the dowel-hole, inclines to form a cushion in the bottom of the dowel hole which effectively resists the driving force. This condition may be offset by the use of spiral grooved dowel.

4. As moisture reduction occurs the diameter of the dowel decreases and that of the dowel-hole increases. To control these movements effectively a strong glue is necessary.

5. Stronger dowel joints result from the double-spread method than from single spread but the strongest joints develop when a splitting agent is inserted into the end of the dowel.

6. Species does not play an important part in joint strength if the dowel is run at low moisture content but the product should be well manufactured.

7. Pressure results from swelling when the moisture content of the wood increases through the application of an aqueous solution of glue. A greater pressure on the glue line than is afforded by swelling alone can be induced by the insertion of a splitting agent, such as a corrugated metal fastener, in the inserted end of the dowel.

8. The strength of a dowel-joint is directly dependent on the glue used and of the pressure applied at time of assembly.

9. Insertion of dowel parallel to the grain of the dowel-head results in stronger joints than insertion perpendicular to the grain.

10. The difficulty of obtaining strong dowel joints is indicated in the low percentage of wood failure which occurs when the joints are fractured.

11. Butt-joints offer greater resistance to tensile loading than is obtained from dowel-joints because effective pressure can be applied at the time of assembly of the butt-joints.

12. Butt-joints offer poor resistance to side-thrust, but resistance can be materially increased by the insertion of dowel.

13. Dowel-joints are unsuitable for assemblies in which end-grain meets radial or tangential grain in the joint. In this form of assembly mortise and tenon joints are to be preferred.

14. Dowels tend to decrease the average strength of edge-joints and are of value only when changes in moisture set up stresses which would cause adjacent boards to warp subject to their freedom of movement in opposite directions.

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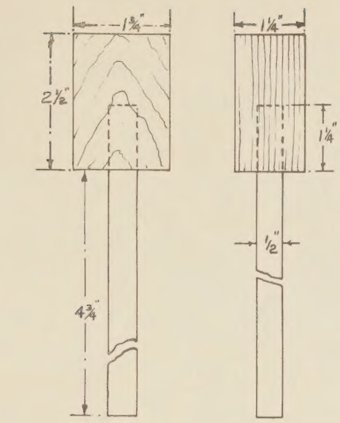


Fig. 1
Dowel insertion parallel to grain

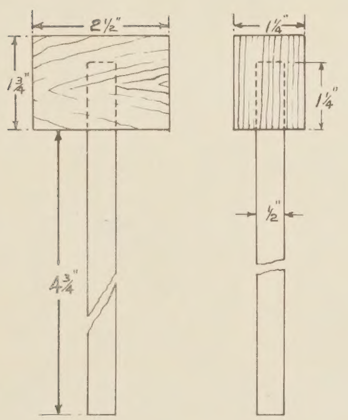


Fig. 2
Dowel insertion perpendicular to grain

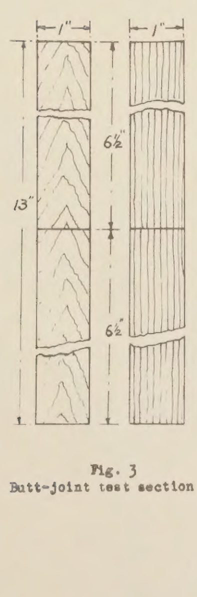
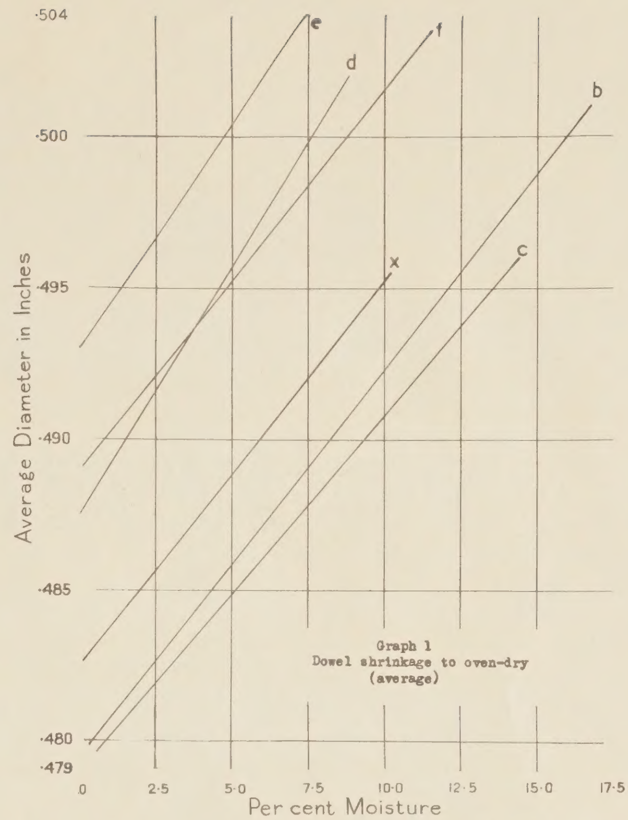
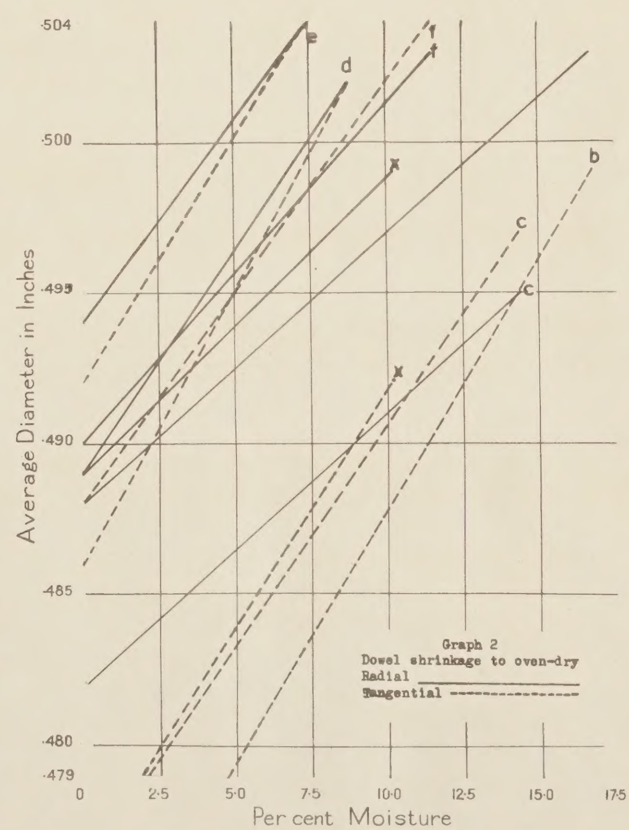


Fig. 3
Butt-joint test section



Graph 1
Dowel shrinkage to oven-dry
(average)



Graph 2
Dowel shrinkage to oven-dry
Radial ――――――――
Tangential - - - - - - - -